RFQ thermal analysis and frequency response

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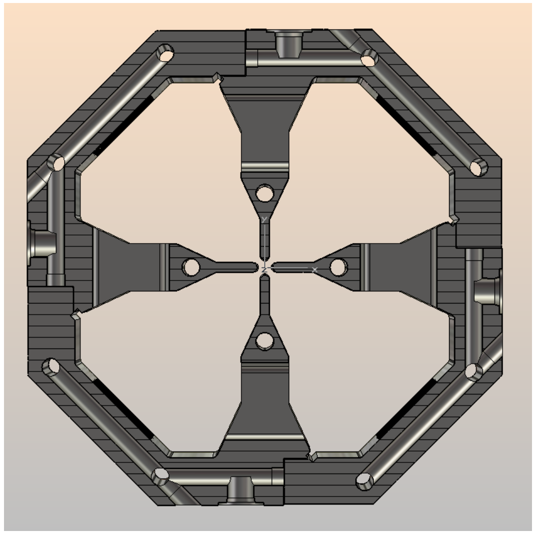
Differential water temperature tuning

HINS, -14.5 kHz/^{o}C

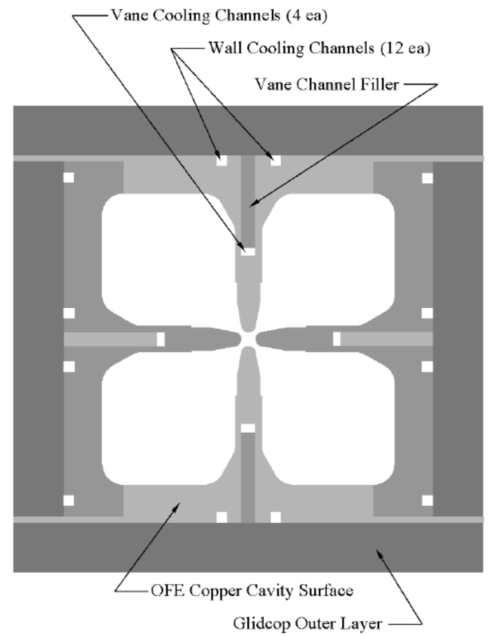


8 channels in the body

R_0 = 3.4 mm for HINS
R_0 = 3.51 mm for SNS

Tuning coefficient does not depend strongly on absolute value of C, since $\Delta F \sim \Delta C/2C$ and ΔC is larger for larger C due to higher sensitivity

SNS, -33 kHz/^{o}C

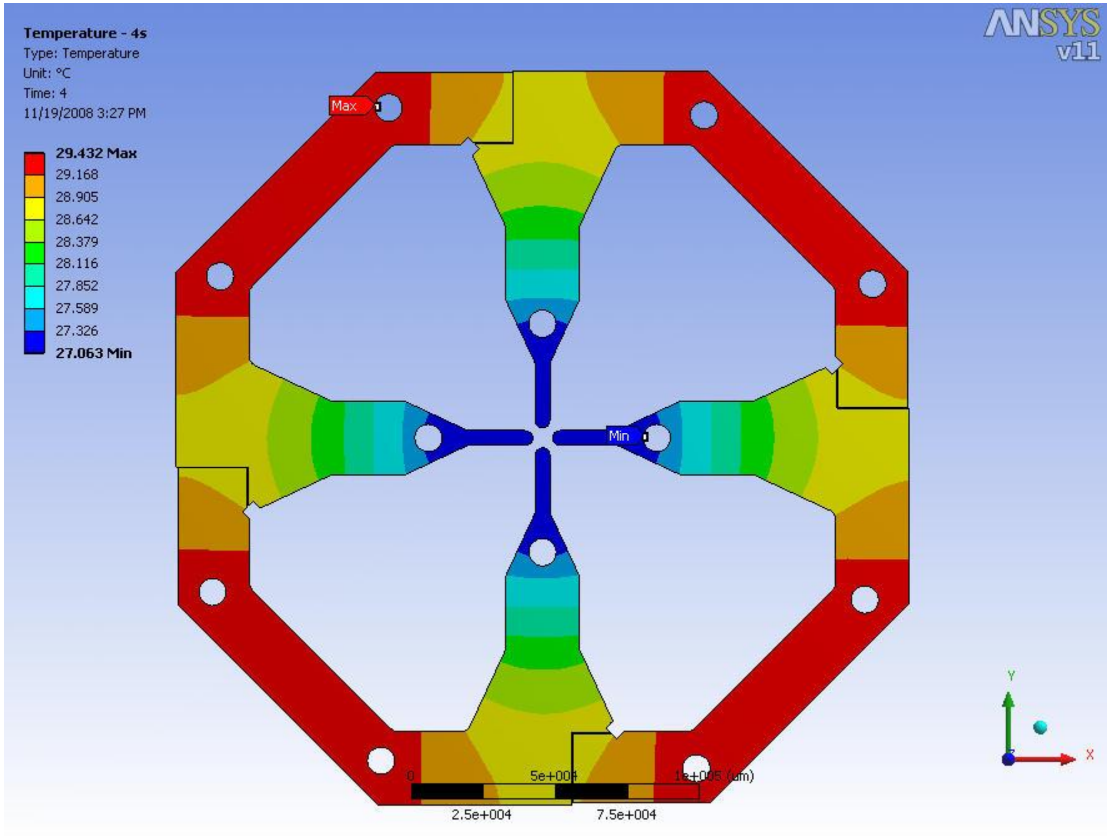


12 channels in the body

In fact operating frequency of HINS RFQ is sensitive to gap variation quite enough for effective differential water temperature tuning:
- If we could change gap by heating or cooling the vanes and keep body size constant, the coefficient would be -54 kHz/^{o}C
-If we could change the body size keeping the size of vanes constant, then the coefficient would be 47.6 kHz/°C (actually we pre-tuned our RFQ using this approach and we know that it is effective)

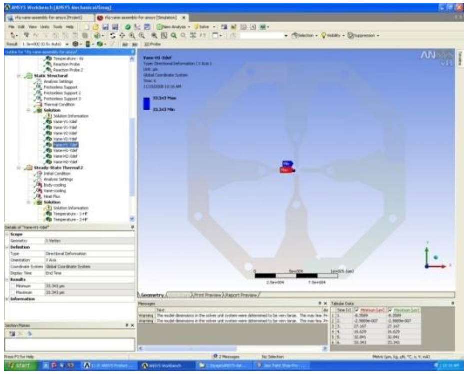
Tom performed thermal analysis for various combinations of water temperatures for body and vanes. The case below shows why differential tuning is not effective for our RFQ

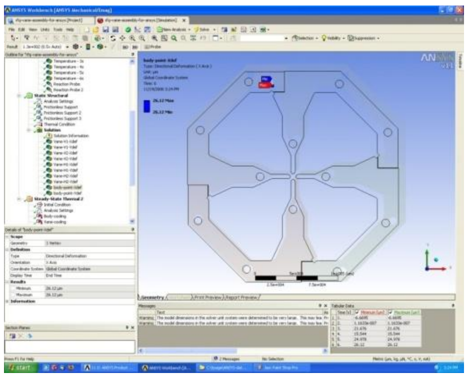
Water temperature in body channels 33^oC
Water temperature in vane channels $20\ ^oC$
Steady state temperature varies over cross-section from $27\ ^oC$ to $29.4\ ^oC$. So, the temperature difference is not just big enough – $2.4\ ^oC$ only.

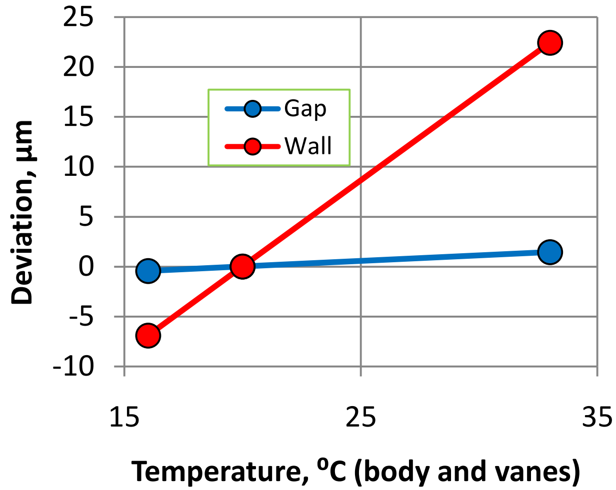


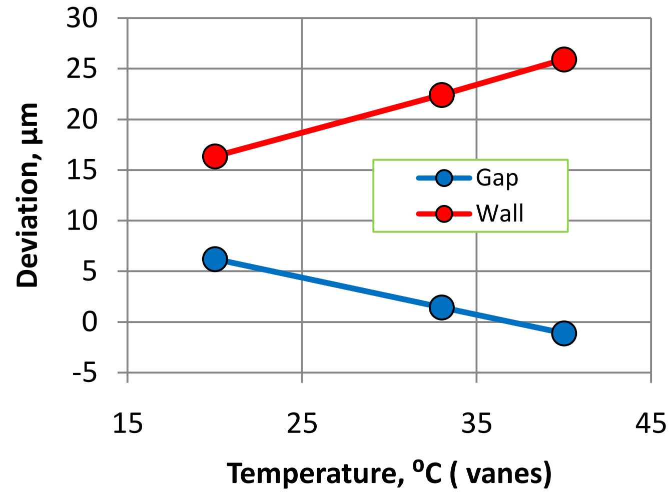
Question: What frequency change we should expect with RF losses and how to compensate it.

Changes of gap and body wall shift at different heat loads









Gap deviation includes wall shift. All functions are linear. Deviation of wall for uniform temperature corresponds exactly to thermal expansion coefficient of copper of 16.9e-6/ºC, and gap deviation actually is a linear function of wall shift: ΔY≈ΔW/15

Load Cases

Case	Body Temp. ºC	Vane Temp. ºC	RF
1	16	16	OFF
2	20	20	OFF
3	33	33	OFF
4	33	20	OFF
5	33	40	OFF
6	33	33	ON

Results

Case	Vertical gap Δ Y, µm	Horiz. Gap Δ X, µm	Body wall shift ΔW, µm
1	-0.4472	-0.4509	-6.896
2	0	0	0
3	1.454	1.465	22.41156
4	6.223	6.258	16.34533
5	-1.115	-1.116	25.91733
6	0.618	0.656	27.036

1-3 – the same temperature of body and vanes

3-5 – body temperature is constant , vanes temperature varies

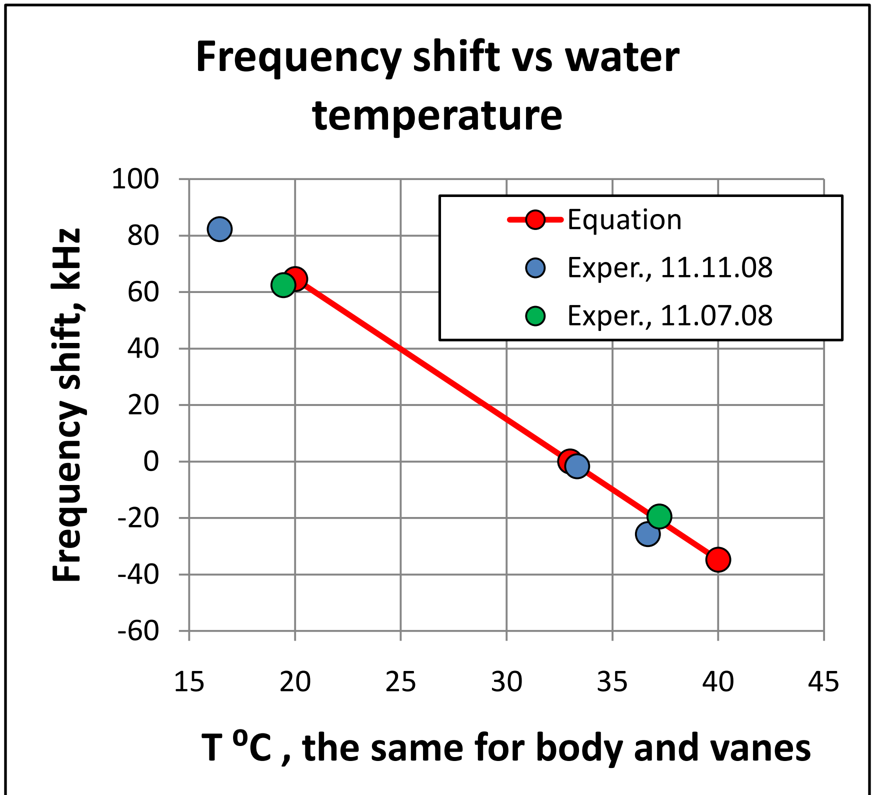
6 – case 3 with RF load of 3.5 kW average added

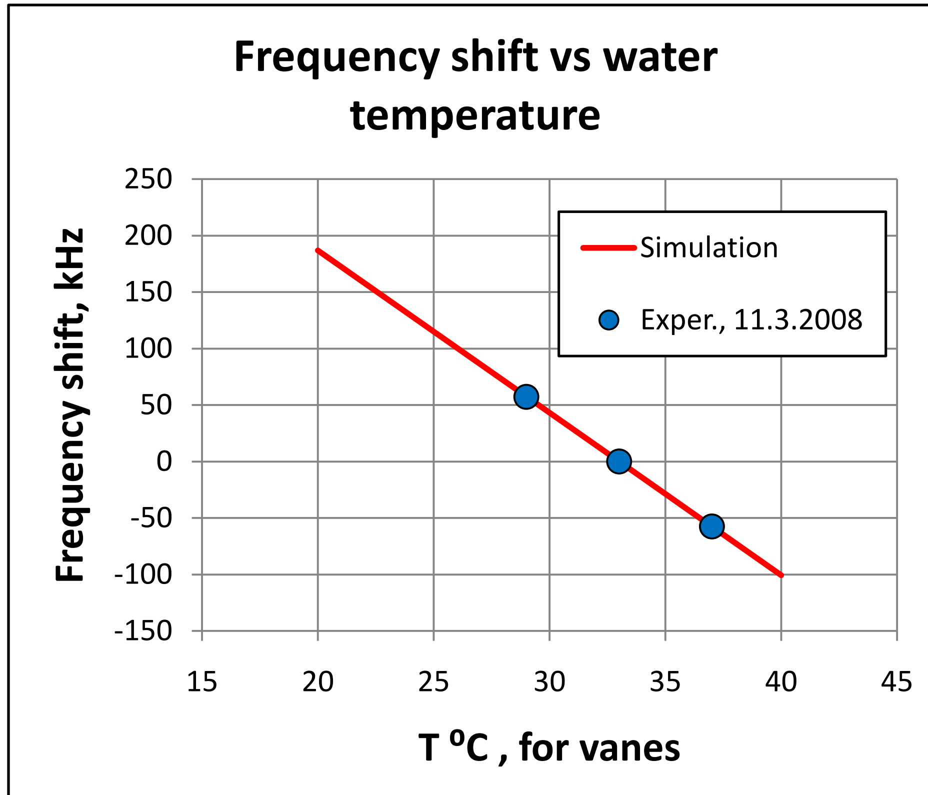
Conversion of deformation to frequency shift

$$\Delta f = \alpha \cdot \Delta Gap + \beta \cdot \Delta Wall$$

Actually for uniform temperature distribution we do not need two parameters since gap and wall deformations are not independent. Let α = 14 kHz/µm (just known value for gap), then using any experimental point we find that β = -3.791 kHz/µm (MWS estimation is -5.5 kHz/µm).

For two independent sources of heat we need two coefficient s for fitting. Solving a system of two equations we find α = 36.2 kHz/ µm and β = -2.33 kHz/µm. Unfortunately we have only one set of data and cannot check how the coefficients change with different initial temperatures of vanes and body.





Conclusion

For average RF load of 3.5 kW we can make three estimations of resonant frequency shift for the RFQ (compare case 3 and 6):

1. Taking into account only average temperature rise over RFQ cross-sections which is 3-4ºC, frequency shift between cases 3 and 6 would be 15-20 kHz.

2. For one parameter fitting based on uniform heating data, the frequency shift estimation is 32 kHz. To compensate this frequency shift temperature of water in vanes and body needs to be decreased by 32/5=6.4 ºC or water in vanes needs to be decreased by 32/14.4=2.2 ºC

3. For two parameter fitting based on differential heating data, the frequency shift estimation is 42 kHz. To compensate this frequency shift the water temperature decrease of 8.4 ºC (vanes and body) or 2.9 ^{0}C (vanes only) is needed